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Some Forms of Apparatus Used in the Course of Practical Instruction in Physiology in the University of Pennsylvania.

BY

EDWARD T. REICHERT, M. D.

FROM
THE UNIV. OF PENNA. MEDICAL BULLETIN
JUNE, 1901

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MAY 1901

SOME FORMS OF APPARATUS USED IN THE COURSE OF PRACTICAL INSTRUCTION IN PHYSIOLOGY IN THE UNIVERSITY OF PENNSYLVANIA.

By EDWARD T. REICHERT, M. D.,
Professor of Physiology, University of Pennsylvania.

The development of practical instruction in medical teaching during the last decade has been so extensive as to necessitate a reconstruction of the curriculum. In no branch has this been more marked than in physiology, and in the University of Pennsylvania the teaching of this subject has undergone such progress and reached such standards in methods and equipment as to attract attention in this country and abroad, and the frequency of inquiries by letter, and of visits to our laboratories by many who are particularly interested in this and kindred subjects have suggested that a brief sketch of at least certain of the forms of apparatus should find acceptance.

The general characters of the equipment must depend, apart from the matter of the cost, largely upon the main objects sought—whether the chief aims are, the illustration of the didactic course, the exhibition of physiologic apparatus and methods, etc. (which can satisfactorily be done in the lecture and demonstration rooms); or whether they are, the training in the use of instruments of precision with especial reference to clinical and experimental medicine, the cultivation of the individual powers of observation and deduction, the encouragement of and insistence upon accuracy of method and expression, the prosecution of collateral work with the view of the co-ordination of facts and their broad application, etc. If the latter, they cannot satisfactorily be attained with crude instruments, which at best are unscientific makeshifts and very

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often merely toys, and generally so regarded by the student. Aside from any other consideration the moral effects attending the use of instruments of precision and the pursuit of broad objects are far more salutary than the inexperienced, as a rule, are apt to believe, and it is perhaps needless to state that this course in the University has been based upon such views, and that time, labor and expense have not been spared to secure the highest results. It must not be supposed, however, that thoroughly satisfactory apparatus and expensive apparatus are necessarily synonymous terms.

The portion of the equipment particularized in this article does not include many instruments which are comprised within the student's individual outfit, or which are used in demonstration or section work, such as muscle and heart clamps, perfusion cannulæ, microscopes, live stages, small centrifugal machines for blood, etc., hemocytometers, hemoglobinometers, urinometers, lactometers, plethsphygmographs, ergographs, dynamographs, galvanometers, electrometers, condensers, polarimeters, artificial eye models, color mixers, gas pumps, chemical apparatus and reagents, etc., most of which are common articles of commerce.

The most important of the fundamental elements in the design and construction of apparatus for a systematic course of practical exercise are: Simplicity, compactness, strength, ease of manipulation, adaptation to a variety of uses, the co-ordination of the designs of the different instruments, precision of operation, and cost. Such a collection of apparatus must necessarily be planned upon a broad and systematic basis: The various instruments should be so methodically designed as to constitute co-ordinate systems, that is, the arrangement of all of the elements of design and construction should be so orderly that each piece and each system is mutually related to the

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others, and forms an integral part of the whole scheme. Moreover, the scheme should be so laid out as to afford the student a well-balanced course in all important parts of physiology, and not, as is often illogically the case, the concentration upon a single subject to the subordination or exclusion of the others.

A part of a set of apparatus constructed upon the above lines and supplied to each of our students will be considered under three headings: I. THE LABORATORY TABLE; II. THE SYSTEM OF RECORDING APPARATUS; III. THE SYSTEM OF EXCITING APPARATUS. All of the instruments were made in our laboratories, and number over 2,000 pieces.

I. THE LABORATORY TABLE.

The design of the laboratory table to be used in practical physiology is worthy of more consideration than is usually given to it, and especially so if, as in our great medical schools, a large number of tables and sets of apparatus are in constant use. The details as to the area and thickness of the top, the height of the table, the size of the drawer or drawers, the kind of wood to be used, etc., are usually the sole matters of concern, yet there are others of not less importance. For instance, in courses of instruction which necessitate the changing of apparatus from day to day, the transportation of dozens or hundreds of instruments between tables and store-room is, even with ordinarily careful handling, very injurious to apparatus. When a large number of sets are to be cared for, as in our own laboratories, in which fifty are in constant use throughout the session, the time, labor and injury involved in these repeated changes become more or less serious matters. In fact, experience gained in the teaching of large classes has shown that an essential feature of an ideal laboratory table is a suitable pro-

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vision for the storage of all, or practically all, of the apparatus used in the entire course of instruction. Apart from the manifest advantages indicated, the

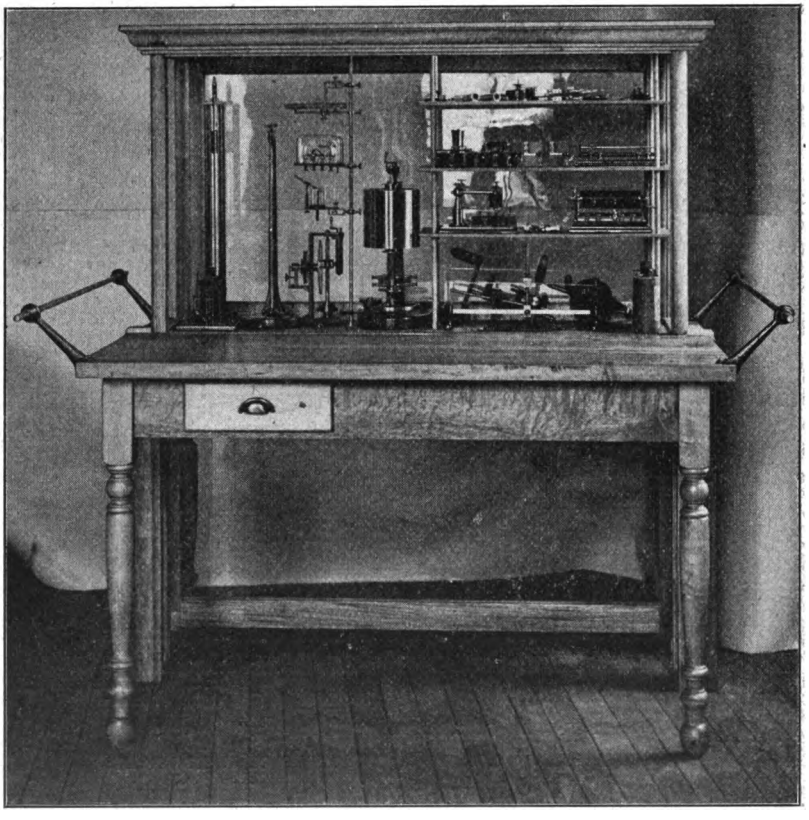

FIG. 1.—The Laboratory Table.

convenience of having every instrument immediately at hand must of itself be a strong recommendation.

A table which admirably meets the requirements of modern instruction is illustrated in the accompanying cut (Fig. 1). It is 3 feet high—a height convenient for the student to work standing. The top is 2 feet

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10 inches deep by 5 feet long, and is made of strips of kiln-dried maple 1¼ inches square, glued together, and pinned through and through with three iron rods, and so clamped to the sides, front and back of the table that neither warping nor cracking is likely to occur. The top projects 2 inches on all sides to permit of the attachment of certain forms of apparatus to the edges. A shallow drawer is placed low in front to the left, so as to be as much out of the way as possible and yet be conveniently located. On each end is a countershaft, the two being coupled by cone pulleys and round belting, thus affording power at both ends of the table and also permitting of the two countershafts being run coincidently at different speeds.

The top of the table to a depth of 2 feet is used for the "setting up" of the apparatus and operative procedures, while upon the back is built a glass case for the storage of the apparatus. The case is 10 inches deep, 30 inches high, and 5 feet long. It has three shelves which extend one-half the length of the case, and a sash in front, which is nicely counterpoised with lead weights and readily moved vertically through an opening in the top of the table. The glass forming the top of the case is flush with the framework, thus avoiding corners for dust to collect in. The arrangement of the apparatus is methodical, with especial reference to convenience and economy of space—"a place for everything, and everything in its place"—each piece being assigned to a definite place, which is labeled with the name of the instrument. To further economize room, one or more vertical rods are provided upon which a number of pieces are clamped. The case is built of glass with the view chiefly of the unobstruction of light.

II. The System of Recording Apparatus.

One of the most important parts of the equipment for practical instruction is the apparatus used for

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making graphic records. Among the instruments included in this system are the following: A kymograph, an adjustable stand, four universal adjustable holders, a small electromagnet for recording comparatively long intervals of time, a Pfeil's or Deprez's sig-

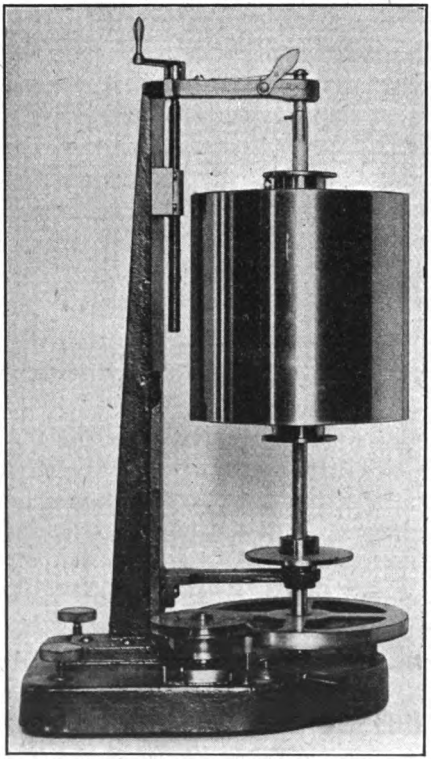

FIG. 2.—The Kymograph.

nal for recording hundredths or two-hundredths of a second, a vibrating reed, muscle and other levers, a frog table with accessories, a muscle chamber, a moist chamber with electrodes, etc., a water manometer, a sphygmograph, a plethsphygmograph, an artificial

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circulation schema, and a tambour. In the kymograph is supplied a desirable form of recording surface, and in the instruments associated with it a variety of means of transmitting and recording movements.

The Kymograph.—The wide range of work to which the kymograph is subjected, in both practical instruction and research, is sufficient of itself to justify a most careful consideration as to its design, and particularly so if a large number are to be provided and the question of expense is a matter of moment. Such problems as the source of power, the form and area of the recording surface, the adaptation to a wide range of speed, the starting and stopping device, simplicity, durability, and cost are not always readily disposed of, and almost invariably certain important points are necessarily more or less sacrificed for gain in others.

A form of kymograph (Fig. 2) which combines a maximum of the most desirable features was devised by the author nearly three years ago, and since that time has been in constant use in our laboratories, over fifty now being employed in class instruction. The upper portion of the instrument, with its devices for holding and permitting the ready removal, the replacement, and the vertical movement of the drum, is essentially a duplicate of that so familiar in the Ludwig apparatus; while the lower portion, in which are the devices for the transmission of power and for the starting and stopping the drum, is but a trifling modification of Sherrington's. This combination of the best qualities of Ludwig's and Sherrington's kymographs makes an instrument that is very simple in construction, compact, strongly built, and with low centre of gravity; that can be used with the drum in either the horizontal or vertical position; that can be started and stopped instantaneously at any part of the revolution of the drum; that permits the drum to be re-

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moved and replaced with perfect facility, and to be raised and lowered without jerk or jar, and without risk of disturbing writing levers in contact with it.

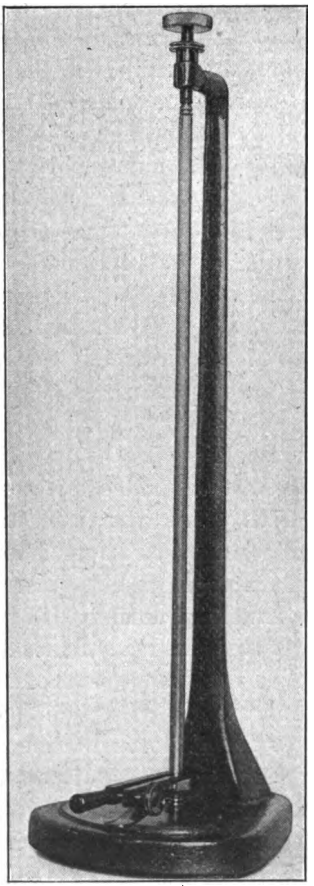

FIG. 3.—The Adjustable Stand.

Any desirable speed that is required in ordinary laboratory work can be obtained by means of cone pulleys and a variable speed gear without change of speed of the main laboratory shafting.

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The source of power is one of the elements in kymograph instruction upon which there are fixed views. Some prefer a self-contained power, such as a clock-work or an electric motor, while others choose power transmitted by belting directly or indirectly from the general laboratory power supply. That each has its advantages goes without saying, and in some instances conditions compel the use of one or the other. But where a choice can be made, which form is to be preferred? The unlimited portability of the kymograph with a self-contained motor seems at first thought to give this form a decided value over that driven by a belt, which necessarily limits the space where it can be used, but this advantage is more imaginary than real, inasmuch as all the portability that is necessary is possessed by the latter form. Moreover, the very important feature of the wide variations of speed required in general laboratory work, durability, and ease of manipulation, have not been satisfactorily solved in a kymograph with a self-contained power that is adapted to students' work. It is a common experience that unless a clock-work is substantially made and carefully used, it soon becomes defective. When, however, the kymograph is driven by belting from the common source of laboratory power, the shifting of a single belt can be made to change the speed from the slowest to the fastest that is likely to be required, and by means of a simple variable speed gear all the finer adjustments of speed can be obtained at will. A form of variable speed gear referred to, consists essentially of a pinion moved vertically in contact with a revolving disc, which was long since adopted by Ludwig in both his large and small kymographs.

Whether or not the student's kymograph should be constructed so as to permit of the use of the drum in both the vertical and horizontal positions is questionable, as any gain over the restricted use in the vertical seems fully offset by the disadvantages that go with it.

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The drum is 6 inches by 6 inches, a size adapted to both physiologic requirements and the dimensions of the glazed paper kept in the shops. The lower end of the drum-shaft fits in the socket of a revolving disc, which is slotted to receive the transverse pin in the end of the shaft. The disc also serves a purpose in conjunction with an automatic key, which is fastened to the standard of the kymograph. A pin is inserted at a convenient point near the margin of the disc, and as the disc and drum revolve, the pin operates with the levers of the key, thus automatically breaking or mak-

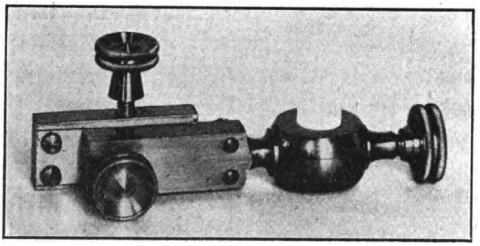

FIG. 4.—The Universal Adjustable Holder.

ing one or more currents, which are used for excitation or other purposes.

The starting and stopping device is simple, strong and effective. The power is thrown on by a slight forward movement of the handle of the lever. A backward movement of the handle throws the power off, and permits the drum to revolve freely by its own momentum, but a slight farther backward movement throws a vertical pin, which is covered with rubber, in firm contact with the face of the large wheel in the front of the kymograph, stopping the movement of the drum instantly.

The Adjustable Stand.—The design of the stand is logically next in order to that of the kymograph, because upon it are to be supported the various forms

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of apparatus which are devised to make records upon the smoked paper of the drum. Moreover, inasmuch as the stand is to hold a number of instruments for very different purposes it is necessary that certain details of its construction be determined upon so that the designs of the stand and attachments be in harmony. The stand as usually made consists of a substantial iron base of sufficient weight and area to give stability, the base having fastened to it a vertical rod 15 to 18 inches long. Upon this rod the various instruments having writing styles are clamped, and the styles are brought in contact with the drum by moving the stand, or the instruments attached to it, to and fro. Adjustment in the way, especially when the pressure of the styles must be regulated to a great degree of delicacy, is in unsteady and inexperienced hands often a tedious task. The stand shown in Fig. 3, which is a modification of the Runné stativ, was designed so as to combine the greatest ease of adjustment with simplicity, durability and cheapness. The rod is supported by a standard having at the top an adjusting screw with a lock nut. Upon the lower end of the rod is a device for coarse and fine adjustments of the writing styles. It consists of two arms coupled like the two parts of a hinge, one being loose and the other fastened to the rod, and their free ends thrust towards each other by a split flat spring at the back. The former has a hard-rubber handle on the end and a strong spring on the bottom which slides upon a smooth surface on the base having the form of an arc of a circle. The tension of the spring is altered by the adjusting screw which holds the rod in the top of the standard, and is made sufficient to maintain the rod in any position of its revolution in which it is placed. The other arm is fastened to the rod, and is moved towards and from its mate by the adjusting screw attached to it, at the same time turning the rod. When

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the handle is shifted to the right or left the whole device, together with the rod, is moved, the tension of the ring spring on the back being sufficient to cause the two arms and rods to move together. In practice, the

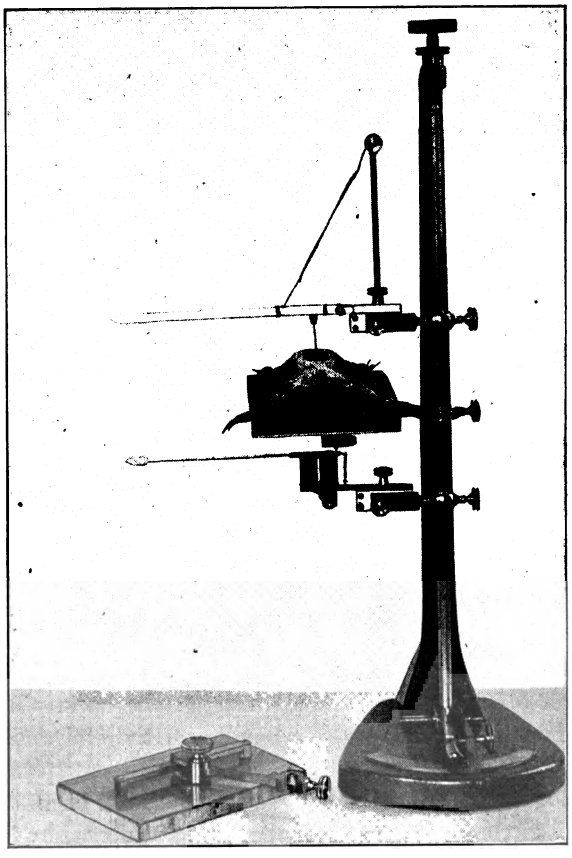

FIG. 5.—The Frog Table.

recording styles are brought in contact, or nearly so, with the drum by moving the handle to the left, and the fine adjustments of contact are obtained by turning the adjusting screw at the right of the handle.

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A movement of the handle to the right throws off the styles to any desirable distance, as, for instance, when it is necessary to remove the drum to renew the recording surface.

The Universal Adjustable Holder.—Instruments which are supported by the stand are not, as a rule, fastened directly to the stand, but by intermediate specially devised adjustable holders, which are so fashioned as to hold quite a variety of apparatus, thus saving the expense of duplication of clamp devices, yet without losing anything in effectiveness. The universal adjustable holder (Fig. 4) consists of a clamp having a short arm, upon which is fastened a strong flat spring carrying a metal block. Near the end of this arm is an adjusting screw by which, in conjunction with the spring, the block is caused to move backward and forward. The various instruments are fastened to the top or bottom of this block, and their styles are thrown forward or backward by turning the adjusting screw.

In using the stand, each instrument is attached to an adjustable holder, which is clamped at a proper height to the rod, and the pressure of the style upon the drum is adjusted by moving the adjusting screw of the support. After all of the writing styles used in the exercise are thus adjusted, all of them can be moved away from the drum by a movement of the handle of the stand to the right, and brought in contact with the drum by the reverse movement. The fine adjustments of the pressure of *all* of the styles can then be made by moving the adjusting screw of the stand, while the variations in pressure of *each* style can be obtained by turning the adjusting screw of the corresponding support. With so simple and thoroughly effective a plan of adjustment the merest tyro can with ease and rapidity obtain the most minute variations in pressure of any one or of all of the styles.

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The Frog Table.—A convenient table upon which a decerebrated frog can be fastened has a wide range of usefulness, especially in studies of circulatory and nerve-muscle phenomena. In Fig. 5 a form of this

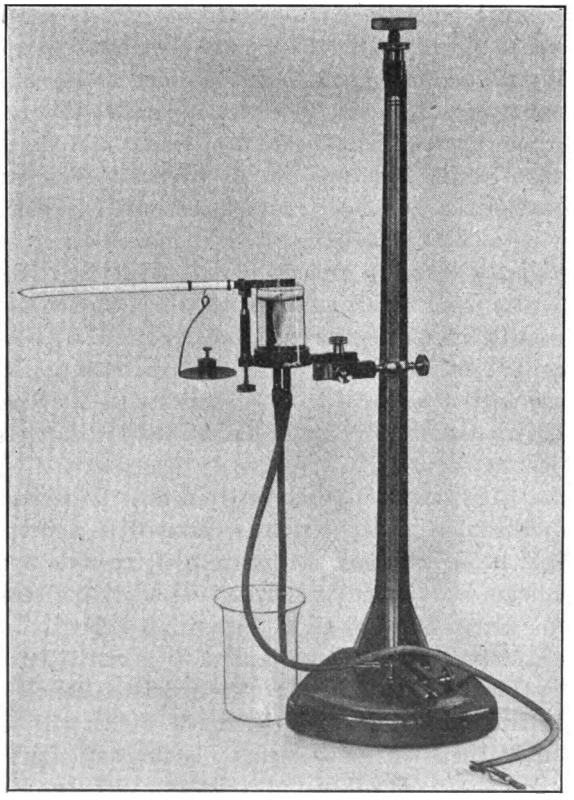

FIG. 6.—The Muscle Chamber.

instrument is exhibited, showing a decerebrated frog in position, and illustrating one of its many adaptations to observations of the phenomena of the heart-beat. The table consists of a brass plate 3 inches by 6 inches, upon which is cemented a piece of cork

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one-half of an inch thick. The whole is supported by a rod having a clamp at each end—that on the one end to fasten to the stand, and that on the other to a square brass rod attached to the under surface of the table. The device is such as to permit of the horizontal movement of the table in all directions, so that any given spot of the top can be brought exactly under any device which is intended to rest upon or to be fastened to the frog's heart, etc. In the figure, the frog's heart is shown exposed, and resting upon it is a small inverted pan attached to a vertical rod, which is connected with a lever, the lever being counterpoised by a thread of india-rubber. The movements of the heart are transmitted to the lever, which in turn are recorded upon the drum of the kymograph. In one corner of the table a hole may be cut, across which opening the web of the frog's foot can be stretched for microscopic examination of the circulation. There is shown in the figure beneath the table a small electromagnet, with which time-intervals (usually seconds) are recorded coincidently with the movements of the lever recording the heart-beats.

The Muscle Chamber.—The Muscle Chamber (Fig. 6) is for the study of the effects of temperature and drugs upon the frog's heart and frog's muscles, and is therefore adapted to a wide range of pharmacodynamic work. The heart or muscle to be studied is fastened in the chamber by a thread attached to one tendon and drawn through an eye in the bottom, and led over the edge of the glass cylinder to the small belaying pins in front, where it is tied. The other end of the preparation is attached by a thread to the muscle lever. The height of the lever can be altered by an adjusting screw in the bottom of the standard to the left. By means of the inlet and outlet tubes the normal saline or other solution in which the preparation is immersed can readily be changed at

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will, and thus solutions which vary in temperature or composition can expeditiously be substituted.

The Moist Chamber.—It is often necessary, and generally desirable, in experimenting with nerve and muscle preparations to adopt precautions to protect them from drying, which soon destroys irritability. This protection is sometimes obtained by immersion in a normal saline solution, defibrinated blood or other liquid, or by painting occasionally with a preservative solution. As a rule, the preparation is placed in an air chamber, the air being kept moist by enclosed

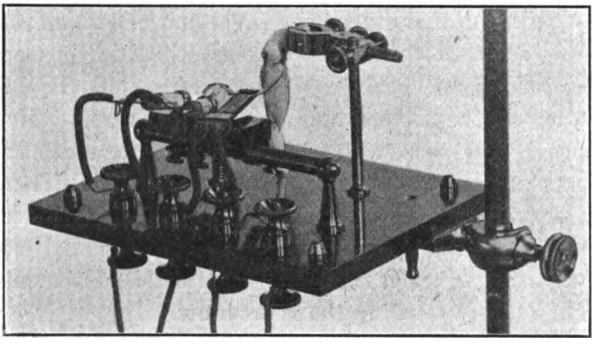

FIG. 7.—The Moist Chamber.

pieces of wet paper or sponge. The moist chamber consists of a hard-rubber base (Fig. 7) to which are affixed appropriate devices for holding and exciting the structures to be studied, and a glass shade. These devices consist mainly of a clamp and two pairs of electrodes, the latter being carried by and movable in all directions upon a horizontal rod, and coupled to the binding posts, which are continuous with corresponding binding posts fastened to the outside of the chamber.

In the figure, the femur of the "nerve-muscle preparation" is shown fastened to the clamp, the tendon

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of the free end of the muscle extending through a hole in the base so as to permit of its being attached to a recording lever. The nerve of the preparation is led over a pair of platinum electrodes (exciting electrodes) to a pair of non-polarizable electrodes (electrotonic electrodes). Wires connect the electrodes with the binding posts within the chamber, these being continuous with the binding posts without, from which wires are continued to the apparatus employed to furnish the exciting and electrotonic currents. The glass cover is not shown in the figure, but is exhibited *in situ* in Fig. 16.

The Signal and Vibrating Reed.—Many reactions occur within intervals of time so brief that it is essential to have some form of apparatus to record periods of one-one-hundredth or one-two-hundredth of a second, or less. A most convenient and effective device for this purpose consists of a vibrating reed (Fig. 8) which makes and breaks a current at these intervals, the interruptions being communicated electrically to a recording signal. The vibrating reed, seen on the right of the figure, has as its most important element a flat, steel spring, one end of which is fastened to the standard, the other end being free and bent downward at right angles and armed with a platinum point, and by appropriate connections kept in vibration by currents passing through the overhanging electromagnet. Beneath the free end of the reed is a cup of mercury. The steel spring, mercury cup and electromagnet are so connected that when the vibrating reed, the signal, and a battery are in a circuit, whenever the free end of the spring is brought in contact with the mercury in the cup the circuit is completed and the current flows through the electromagnet of the signal, drawing downward a steel plate which carries the writing lever; the current at the same time passing through the electromagnet of the

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vibrating reed draws the end of the spring out of the mercury, thus breaking the current and causing an upward movement of the steel plate and lever of the signal. The elastic reaction of the spring causes it again to come in contact with the mercury, again completing the circuit, with the consequent repetition of the effects just mentioned, and so the vibrations are continued as long as desirable. The signal thus thrown into vibration by the repeated make and break

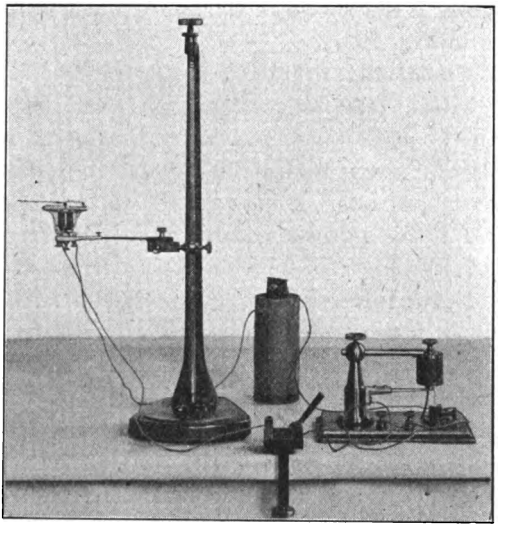

Fig. 8.—The Signal and the Vibrating Reed.

of the current records a series of waves upon the kymograph, each wave having a value of one-one-hundredth or one-two-hundredth of a second, depending upon the vibratory value or pitch of the spring.

III. The System of Exciting Apparatus.

The system of exciting apparatus is of not less importance than the recording apparatus. Naturally, all of its parts must be subordinate to the kind of

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stimulus to be employed, and inasmuch as electricity is universally recognized as being superior for general work to all other forms of excitants, it necessarily is the basis. Such a system comprises three groups of instruments: One for the regulation of the *strength* of the current, including an inductorium, a rheocord and a rheonome; a second, for the *making* and *breaking* and *changing of the direction* of the current, including two Du Bois Reymond keys, a simple contact or mercury key, a double automatic key, a tetanometer and a commutator; and a third, for the *application* of the current to the structures to be studied, including both simple and non-polarizable electrodes.

The Inductorium.—This instrument is among the most useful and essential of all forms of apparatus, and, therefore, demands the most careful study of all of its details. The various forms in use are but modifications of the historical inductorium of Du Bois Reymond, and are structurally based upon the fact that whenever an electric current is made or broken in a coil of wire similar currents are induced in second coil if close by, and that the farther the coils are apart the weaker will be the current in the second coil. The electrodes being connected with the latter, it is obvious that the strength of the current introduced into the living tissues can be regulated merely by moving the second or secondary coil towards or from the first or primary coil. Approximately, the strength of the current through the electrodes varies inversely as the square of the distance of the secondary from the primary coil.

In the inductorium as commonly designed the coils and binding posts, etc., are fastened upon a board usually about three inches wide and from twenty to forty inches long, the primary coil and binding posts, etc., being fastened to one end, while the secondary coil is movable to and fro along grooved guides at the

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sides. In the most recent and improved form (Fig. 9) the secondary coil is moved vertically between two

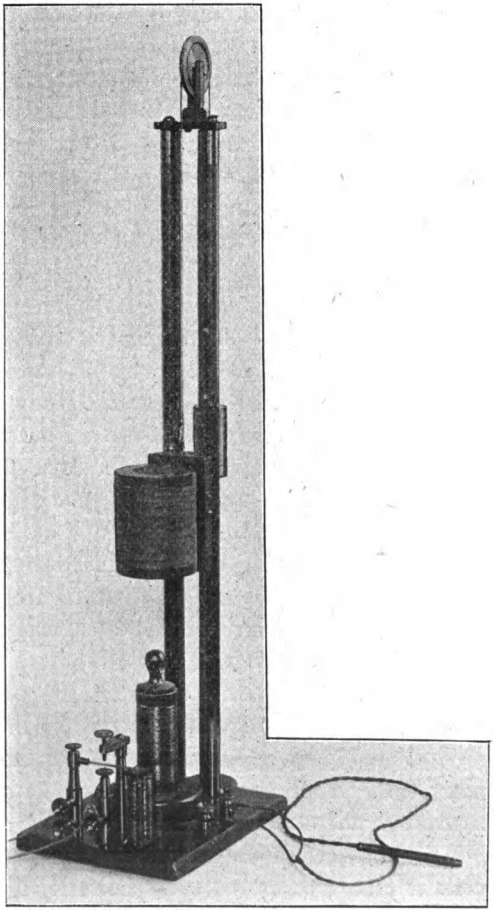

FIG. 9.—The Inductorium and the Hand Electrodes.

brass rods, one of which is calibrated in millimeters, and the other in units of current strength. The coil is conterpoised, and can be moved up or down readily

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by light pressure of a single finger. The primary coil, binding posts, etc., are fastened to an iron base. This base takes up little table-room, and being of metal the difficulties encountered in the warping and other changes in wood are avoided. A core of soft iron wire in the primary coil can be removed if it is desirable to lessen the strength of the current. The binding posts with Neef's hammer, etc., are arranged as in the standard form, so that connections can be made for isolated or rapidly repeated stimuli, for equalizing the "make" and "break" stimuli, for the primary or secondary currents, etc.

The Rheocord.—The rheocord is a device for dividing a current of electricity into two parts, so that more or less of a main current is led off in a "deriving circuit." It is useful chiefly in the measurement of animal currents by compensation, and in studying Pflüger's law of contraction.

The instrument here described (Fig. 10) is the outcome of the need of a form that is compact, simple, convenient in operation, durable and not expensive, and that will furnish an uninterrupted gradation of current in the deriving circuit from a minimal to a maximal strength.

The resistance wire, which is of German silver and about 12 metres long, is coiled around a hard-rubber cylinder two inches in diameter. The coils are sunk in grooves of sufficient depth to allow for the expansion and shrinkage of the wire without danger of the coils being displaced and coming in contact. Each end of the resistance wire is fastened to a face-plate at the end of the rubber cylinder, through these plates circuit contacts are made with the standards, and from the standards the circuit is continued to the two binding screws on the left, to which the wires from the battery are connected, thus completing the main circuit. This circuit is tapped by wires leading from

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the two binding posts on the right: One wire runs to the left binding post of the main circuit; the other wire to a square brass rod which is screwed to the hard-rubber base. The circuit is completed between this rod and the coils of wire by a vertical bronze spring, this being fastened to a hard-rubber block which is carried laterally on a brass screw. The screw is connected by gears with the rubber cylinder in such a way that each revolution of the cylinder causes a revolution of the screw, and thus the vertical spring is moved along in exact relation to the spiral movement

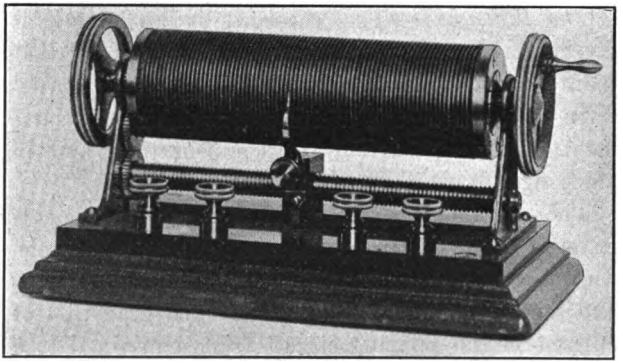

FIG. 10.—The Rheocord.

of the coils of wire. The screw is insulated on the right standard by a hard-rubber bushing, thus preventing a short-circuiting of the main current between the standards. The strength of the current in the deriving circuit varies with the ratio of the resistance in the main and deriving circuits, this being determined by the lateral movement of the vertical spring contact above referred to.

The plan of the connections in detail (Fig. 11), the directions of the currents and the mode of operation of the rheocord are as follows: One wire from the

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battery (positive pole) is led to post 1, thence to standard S_1. The circuit is continued through the standard to the plate on the end of the rubber cylinder, thence to the resistance coils to the opposite plate and standard S_2, thence to binding post 2 and to the battery, completing the main circuit. The deriving circuit is formed by connecting binding post 1 with binding post 4, the circuit being continued by one electrode to the muscle, nerve or galvanometer, etc., thence by the other electrode to binding post 3, to the spring contact C, to the resistance wire, to the standard S_2, to binding post 2, to the battery, and to binding post 1. The main current is divided at binding

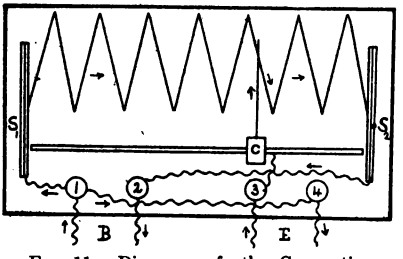

FIG. 11.—Diagram of the Connections, etc., of the Rheocord.

post 1, a part being led through the whole length of the resistance wire, and a part through the portion of the resistance wire between the contact C and standard S_2, this portion varying with the position of the contact, the farther the contact to the right the less the resistance wire in the deriving circuit and the stronger the derived current. The directions of the currents in the two circuits are indicated by the directions of the arrows in the diagram.

When the rheocord is used in measuring the electromotive force of animal currents the tissue yielding the current, and an electrometer, are placed with the electrodes in the deriving circuit, and the current

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from the tissue run in an opposite direction to the derived current from the main circuit. The vertical contact C is moved laterally until the indicator of the electrometer stands at zero, showing that the potentials of the animal and derived currents are equal. Knowing the electromotive force of the battery, the resistance of the coils of wire, and the ratio of the resistance in the main and derived circuits, the potential of the animal current is easily determined.

The total resistance of the resistance coils is about twenty ohms. This can readily be increased or de-

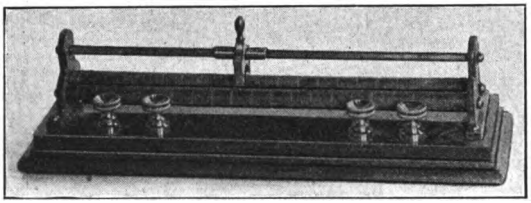

FIG. 12.—The Rheonome.

creased by varying in size and quality of the wire, or increased by introducing a rheostat in the main circuit.

An iron base of sufficient weight is provided to avoid the necessity of clamping to the table.

The Rheonome.—The rheonome has two important uses: (1) to show that it is not the absolute strength of the galvanic current, but sudden changes in its intensity which excite nerves; (2) to modify the strength of current in studying Pflüger's law of contraction. A new and convenient form (Fig. 12) consists essentially as follows: Two grooved hard-rubber rods and a brass rod with slider are supported by two standards. The latter are fastened to a rubber base, and this in turn to an iron base. The grooves are filled with distilled water having a trace of sulphuric

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acid. The battery is connected (Fig. 13) with the binding posts 1 and 2, a simple mercury key intervening on one of the wires. The circuit is completed by a wire running from binding post 1 to the water in one of the grooved rods, thence by the metal slider to the water in the other rod, and thence by wire to binding post 2. Wires are run from these binding posts to binding posts 3 and 4, from which the electrodes are led to the nerve. By these connections the battery current is divided, and the strength of the derived current is increased or decreased by moving the slider to and fro, thus varying the resistance in the main circuit. As the slider is moved to the right more resistance is thrown into the main circuit, conse-

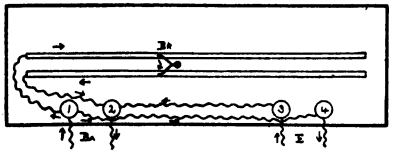

FIG. 13.—Diagram of the Connections, etc., of the Rheonome.

quently a stronger current is driven through the deriving circuit.

In using the rheonome the slider is moved to the extreme left, thus causing practically all of the current to pass through the main circuit, and a correspondingly small part through the deriving circuit and electrodes. The key is opened and closed, and if the current in the latter circuit be not sufficiently strong to cause reaction in the nerve the slider is moved to the right until the opening and closing of the key is followed by feeble reaction. Upon now closing the key and obtaining reaction the current continues to flow through the nerve, and the slider can be moved to the extreme right without apparent effect, notwithstanding that the intensity of the current pass-

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ing through the nerve has been very much increased, as will be obvious by the maximal reaction that will occur upon opening the key, and thus suddenly changing the strength of the current. If the slider be

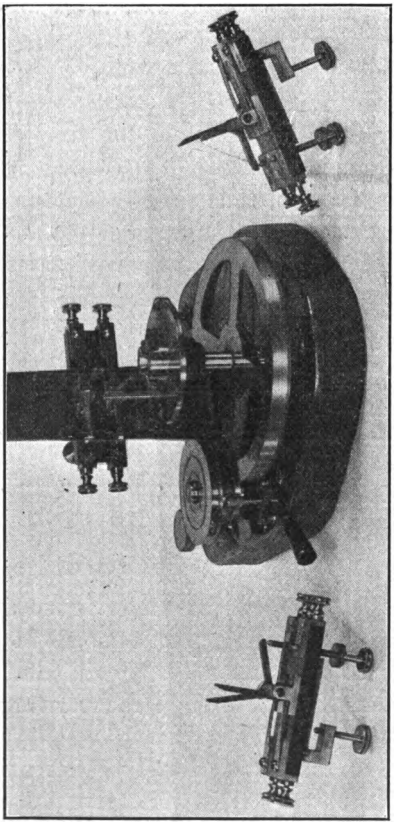

Fig. 14.—The Double Automatic Key.

moved suddenly reaction will occur for the same reason.

The rheonome is in principle a sliding rheocord, the water serving as the resistance medium instead of metal.

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The Automatic Key.—The automatic key is particularly useful when it is desirable to introduce stimuli at specific time intervals, especially in studying fatigue phenomena and the effects of summated stimuli. It is usually so constructed as to be operated automatically by movements of the recording apparatus, and when applied to the kymograph it is attached to the standard and so arranged that as the drum revolves the key is thrown open at definite periods, and thus an induction shock or shocks sent into the nerve or muscle. The key is preferably double (Fig. 14), and so constructed that the intervals between any two stimuli can be adjusted to any desirable fraction of a second. In the accompanying cut, in one view the key is shown attached to the kymograph, and in two views lying upon the table at the side of the kymograph. The L-shaped piece of the key is pressed upon at the point of junction of the two arms by a spring shown in the two views of the instruments upon the table, the purpose of which is to keep one end of the L in contact with the long adjusting screw which penetrates the hard-rubber base. The current circuit is from the binding screw on the left through the metal spring to the L, thence to the adjusting screw and binding screw on the right. The contact of the end of the L with the adjusting screw is broken by the movement of the vertical pin in the disc which holds the shaft of the drum, and the keys can be so adjusted on the standard that the circuit is momentarily or permanently broken. One end of the L is shorter than the other, so that when only one current is used the other half of the key can be thrown out of action, as shown in the figure on the right, the vertical pin striking in its revolution only the L with the longer end projecting. When summated stimuli are used, the adjusting screws are turned until the two free ends of the Ls are no longer

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in the perpendicular, so that the pin strikes one L in advance of the other, the time interval depending upon the rapidity of the revolution of the drum and the distance separating the free ends of the two Ls.

The Tetanometer, or Tetanus Spring.—The tetanometer is designed especially for the analysis and synthesis of incomplete and complete tetanus. It consists essentially of a long, flat steel spring (Fig. 15) clamped to an adjustable support, which slides to and fro on a square rod attached to the standards. The

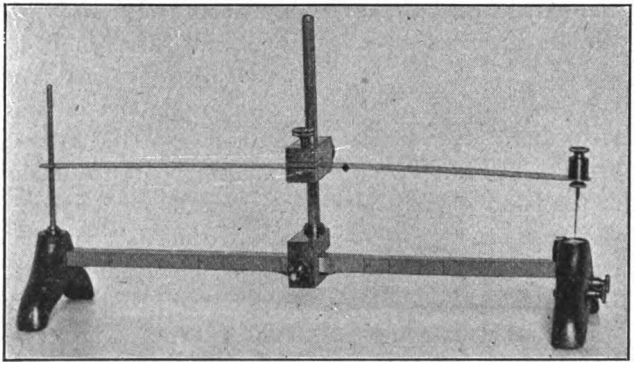

FIG. 15.—The Tetanometer.

left end of the spring is perforated, through which projects a vertical pin, this permitting movement of the spring vertically but not laterally. On the right end is a piece of platinum wire, fastened at right angles to the spring, also a weight to give greater force and duration to the vibrations of the spring. The cup beneath contains mercury. The end of the platinum wire when the spring is at rest does not touch the mercury, but moves into and out of the mercury when the spring is in vibration. The spring and mercury cup are connected in the battery circuit of the inductorium, and the current is made and broken by the

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movements of the platinum wire into and out of the mercury, causing corresponding induction currents. The number of vibrations per second is regulated by changing the length of the spring between the support and the mercury cup, movement of the support to the left or right lengthening or shortening the part of the spring in vibration, and consequently decreasing or increasing the rate of vibrations. The square rod which carries the support and spring is calibrated, so that the spring can expeditiously be adjusted for any desirable number of vibrations from three to thirty or more. The strength of the current is so regulated that only the "break" shocks are effective, thus eliminating complications caused by double stimuli (both "make" and "break" shocks), especially when low rates of vibration are employed. To prevent oxidation of the mercury, and consequent irregularities in the strength of the current, the surface of the mercury is covered with 20 per cent. alcohol.

Apparatus set up for an Exercise.—In Fig. 16 is shown a group of instruments as set up by the student for the study of the various phenomena of a simple muscular act or twitch. Pictured from the left to the right in order are: A kymograph; a simple mercury key; a stand supporting a moist chamber, muscle lever with weight-pan and weight, an electromagnet and a signal; a single dry cell, a Du Bois Reymond key, a vibrating reed, two dry cells, and an inductorium.

The kymograph is so connected with the source of power that the drum revolves at the rate of about forty to fifty revolutions per minute. A muscle preparation, usually the gastrocnemius, is clamped to the muscle chamber and connected with the electrodes attached to the inductorium. The free end of the muscle is fastened to the muscle lever and a weight-pan with weight. The simple mercury key and elec-

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tromagnet are connected in the battery circuit of the inductorium, so that the moment the circuit is closed and the induced current sent through the electrodes into the muscle the electromagnet is acted upon and the instant of stimulation recorded upon the drum, while the movement of the muscle lever records the

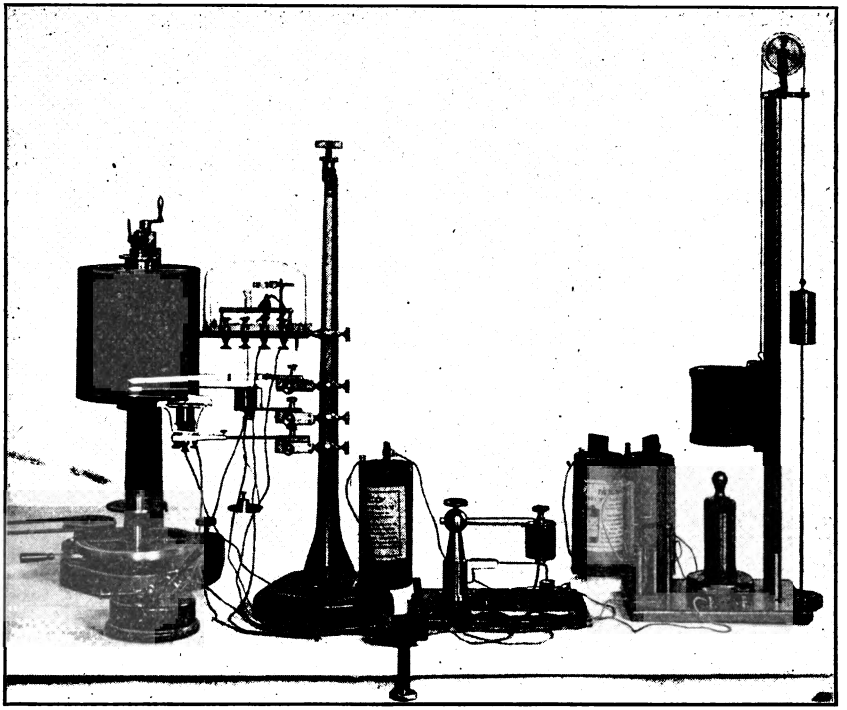

FIG. 16.—Apparatus set up for the Study of the Phases of a Single Muscular Contraction or Twitch.

moment of the mechanical response of the muscle to the stimulus. The intervals of time (one-one-hundredths or one-two-hundredths of a second) are recorded by the vibrations of the lever of the signal, caused by the interruptions of the current transmitted from the vibrating reed. The Du Bois

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Reymond key in the circuit with the signal and vibrating reed is, of course, to open and close the circuit. Thus are mechanically and precisely recorded the moment of the stimulation of the muscle, the moment of the mechanical response of the muscle, the various peculiarities of the several periods of the twitch, and the time interval of each period.

The outlines of the course will form the subject matter of a subsequent article.

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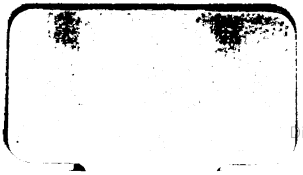

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